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An Automatic, Computer-Operated  
Laboratory Precalibration System  
For Navy Sonar Standard Transducers

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James A. Tims

and

Larry E. Ivey

*Transducer Branch  
Underwater Sound Reference Detachment  
Naval Research Laboratory  
P.O. Box 568337  
Orlando, FL 32856-8337*

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13. ABSTRACT (Maximum 200 words) An new automatic precalibration/quality-control system for laboratory standard transducers is in operation in the Standards Section, Transducer Branch, at the Underwater Sound Reference Detachment of the Naval Research Laboratory, in Orlando, FL. The system automates the measurement of the low-frequency free-field voltage sensitivity (FFVS) of a transducer and the broadband preamplifier voltage coupling gain of a hydrophone preamplifier. Additional automated measurements include impedance and admittance tests from 100 Hz to 40 mHz. The test system is centered around the Hewlett Packard 4194A impedance/gain-phase analyzer.				
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# **An Automatic, Computer-Operated Laboratory Precalibration System For Navy Sonar Standard Transducers**

## **INTRODUCTION**

All underwater transducer standards used by the U.S. Navy and its contractors are calibrated before being put into use. This calibration process is performed by the Naval Research Laboratory, Underwater Sound Reference Detachment (NRL-USRD), Orlando, Florida, in the Calibration Section test facilities. Before the transducers are officially calibrated, NRL-USRD Standards Section first carefully inspects them and then puts them through a series of extensive electrical quality-control (QC) tests. These QC tests, designated precalibration (precal) tests, consisted of a single frequency capacitance measurement, high-voltage DC resistance measurements, and a test for audible response. Many transducers passed these precal tests but failed to function properly when tested by a full calibration. These failures caused an extra expense to the Standards Section because standard transducers then had to be repaired and recalibrated. Since the NRL-USRD Standards Section did not have the facilities required to conduct full acoustical calibrations, additional precal tests were needed to determine the actual condition of the transducers.

While these precal tests were useful in determining the condition of a given transducer, the number of calibration failures showed that the precal tests could not certify that the transducer would perform as desired. This probability can be increased via a precalibration test of the quasi-free-field voltage sensitivity (QFFVS), impedance, or admittance over a predetermined critical bandwidth for a given transducer.

The Hewlett-Packard 4194A Impedance/Gain-Phase Analyzer Measurement System (Fig. 1) was installed in the NRL-USRD Standards Section. This system performs the additional precal tests needed to establish the working condition of the standard transducer prior to the full calibration.

## **EQUIPMENT CONFIGURATION**

The precal measurement system is centered around the Hewlett-Packard 4194A Impedance/Gain-Phase Analyzer. Figure 2 is a basic diagram of the system. All components of the measurement system are controlled by a Hewlett-Packard Series 9000 Model 310 computer with three types of mass storage media. There are two hard drives: a 20-megabyte (Mb) hard drive which is used for program storage, and an 80-Mb hard drive. The second medium is a single floppy-disk drive, which is available for data or program storage. The third medium is an HP-9144A streaming tape drive, which is used to regularly back up the system. The 80-Mb hard drive holds the data base in which all transducer data are stored. The data can be stored to one of the other drives if desired.

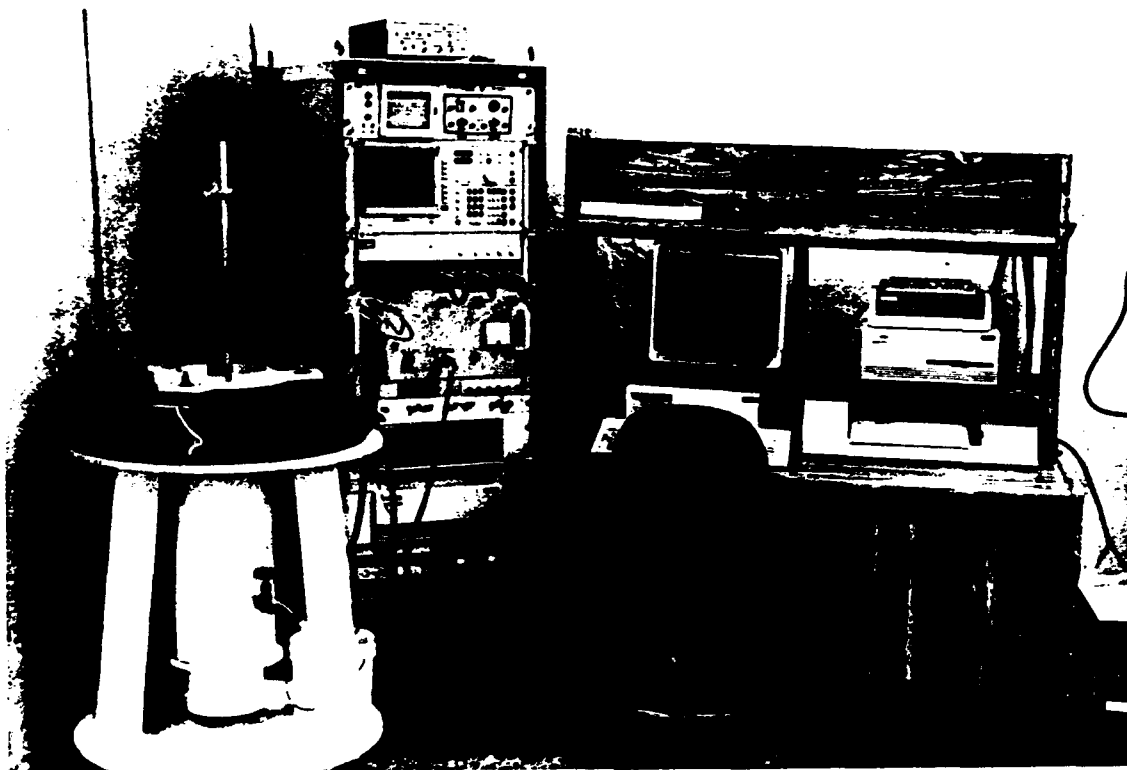


Fig. 1 - Impedance/gain-phase analyzer measurement system.

An HP-59307A dual VHF switch is used to switch the reference input and output of the analyzer for the different gain-phase tests. This switch allows the different tests to be executed without the need to manually change the connections to the hydrophone. All switching is done under computer control.

There are two output devices on the present system. An HP-7475A multi-pen plotter is available to produce charts, and a Think-Jet printer is available to produce charts or tabular copies of the data.

An input/output (I/O) or precal panel was constructed to allow easy connection to the system inputs. The I/O panel has a built-in dual-voltage DC power supply to power hydrophone preamplifiers and a built-in precision 10-ohm resistor and toroid to provide an accurate coupling signal for measuring coupling gains [1]. The precal panel also contains a fused current meter for monitoring the preamplifier current draw.

A USRD laboratory calibrator is connected to the analyzer system via a feedthrough panel. The calibrator is used as a driver to establish a continuous wave (cw) sound field for a comparison calibration [2] at frequencies between 100 Hz and 1 kHz. (Higher frequencies could be attained, but the limit is due to the boundary conditions of the calibrator.) The system can be used with either the G19 [3] or the G40 [4] calibrator. The maximum diameter of the transducer that can be used in the G19 is approximately 4 cm, and approximately 10 cm for the G40.

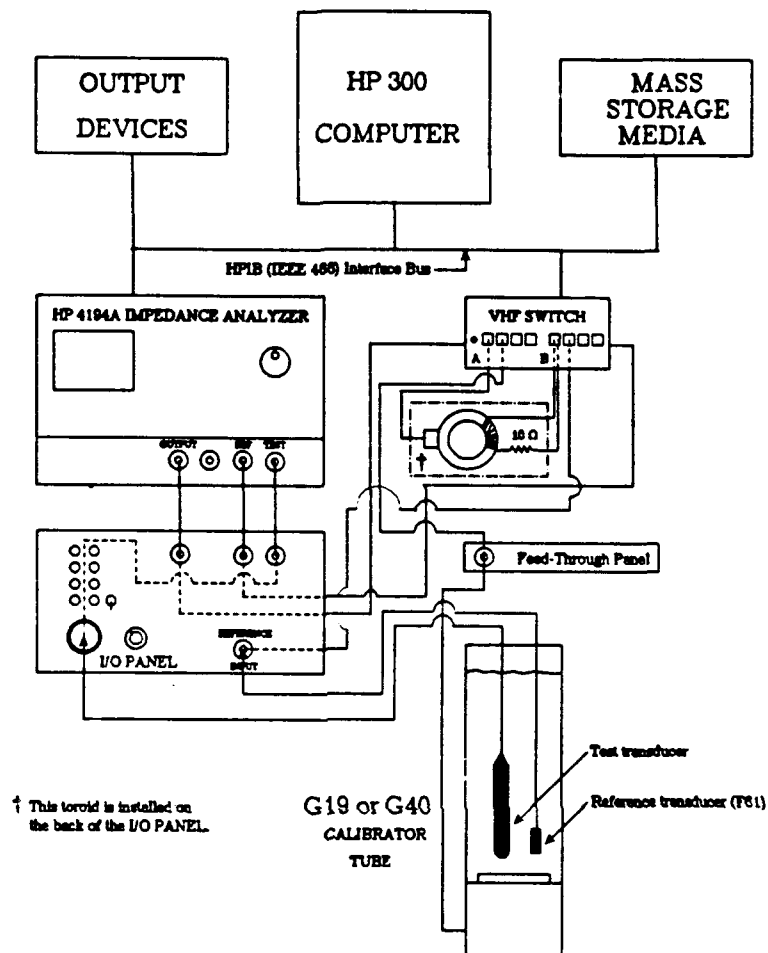


Fig. 2 - Block diagram of automatic measuring system.

All of the equipment is not required to make the measurements. For instance, the system could operate with a single hard drive and without the plotter. The configuration described is a compact system that is easily maintained and performs well.

### SYSTEM CAPABILITIES

The present measurement system software is comprised of two separate computer programs (written in HPBASIC) used to control the measurements. Each of these programs allows two measurements to be taken. The gain-phase measurement program (GPM) consists of a coupling test and an QFFVS test. The immittance measurement program (IMMITTANCE) encompasses an admittance test and an impedance test.



Even though the HP-4194A analyzer is capable of a number of different transfer functions, only the test channel/reference channel function is used for the GPM tests. The coupling points test measures the preamplifier gain at nine preset frequencies covering the bandwidth of the preamplifier. The coupling sweep test measures the preamplifier gain over a bandwidth and step increment input by the user. The QFFVS test is a cw acoustic test conducted in a USRD calibrator. A calibrated standard USRD type F61 transducer is placed in the calibrator with the transducer or device under test (DUT) to conduct a low-frequency comparison calibration [2]. The result is the QFFVS of the DUT in dB (re 1 V/ $\mu$ Pa) from 100 Hz to 1 kHz.

The most helpful tests for troubleshooting transducers are the admittance and impedance measurements. The HP-4194A analyzer can make immittance (admittance and impedance) measurements from 10 Hz to 40 MHz [5]. This bandwidth exceeds that of most transducers and is therefore well suited for this task. The output consists of the magnitude and the phase angle. The resonance frequency is located where a maximum admittance or a minimum impedance occurs. Defective or damaged sensors can be identified by comparing the resonance frequency of the sensor under test to that of a "typical" sensor. The traces can be superimposed on the analyzer screen for direct comparison.

## SOFTWARE OVERVIEW

The software uses the Hewlett-Packard Hierarchical File System (HFS) to organize the data base. Directories are created for each type of transducer using the HFS format. All data for a specific transducer are stored in a directory with the transducer nomenclature (example: all H52 data are in the H52 directory). Also stored in the data base are the test parameters to set up the analyzer for the various measurements and the data for a "typical" sensor element. These are retrieved at test time to properly configure the analyzer for the selected test and transducer. The transducer name and serial number are entered at the beginning of the programs for this purpose. The name and serial number are used for creating the data file name as well.

There are numerous options available to the user during the course of any measurement (Fig. A-3). The sweep boundaries can be altered as can the frequency increment for the measurement. Other parameters of the configuration that can be changed are the output level, the "integration time," the "averaging number" [5], and the attenuation level of the test input (gain-phase mode only). These options can be altered from the computer console with a few keystrokes. The software gives instruction to the user on a step-by-step basis to progress through the measurements.

There are also optional ways to view the data. The data can be plotted or can be printed in tabular form; also, the data can be stored on a floppy disk or to the hard disk drive (default).

The file name for the data is created automatically from the transducer name, serial number, and the date. Once stored, the data can be retrieved and the output reproduced at any time.

The Appendix presents a more detailed description of the software using flow charts of the two measurement programs. Described are flow charts for the general measurement program, the GPM program, and the IMMITTANCE program. Also included is the flow chart to change the sweep parameters (a portion of the GPM program).

## MEASUREMENT METHODS

### Coupling Tests

The coupling tests measure the preamplifier gain or loss at the end of the cable [1]. The measurement is made by inserting a calibration signal in series with both the transducer element (usually a piezoelectric sensor) and the preamplifier input (Fig. 3). A calibration resistor (typically 10 ohms) is included in the preamplifier to provide terminals for injecting the calibration input voltage. This voltage is measured across a second calibration resistor (also 10 ohms) included in the I/O panel. The ratio of the preamp output voltage to the input calibration voltage is the coupling gain. This is based on the theory that the current through the calibration resistor in the preamplifier and the calibration resistor in the I/O panel are the same. A toroidal transformer is used to isolate the calibration signals from the analyzer output. The resulting gain or loss is displayed in decibels on the analyzer screen. The coupling points test displays the data in tabular form since only nine points are measured.

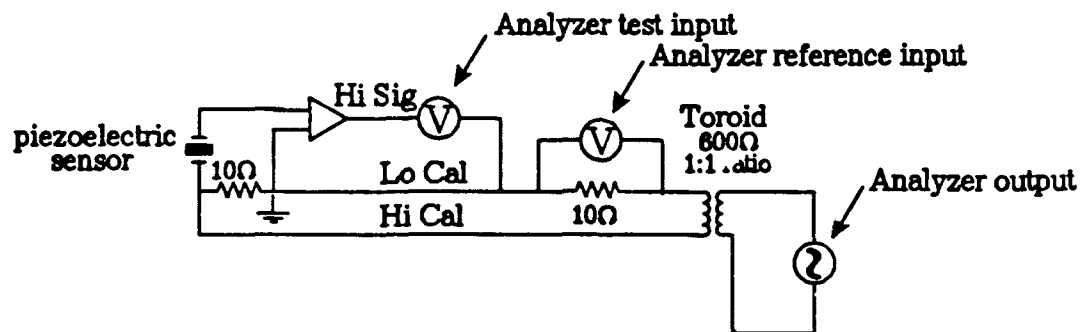


Fig. 3 - Typical calibration circuit to measure coupling gains.

### Quasi-Free-Field Voltage Sensitivity Test

This QFFVS test is done via a comparison calibration [2] conducted in a USRD G19 or G40 calibrator tube. The comparison calibration involves subjecting the DUT and a calibrated reference standard transducer (USRD type F61) to the same acoustic pressure. The HP-4194A measures the output voltages of both the unit under test and the reference standard transducer and takes a transfer function of the voltages yielding the result in decibels. These data are transferred to the computer and combined algebraically with the calibration data of the reference standard transducer (Fig. 4). The resulting data are a close approximation of the FFVS of the DUT.

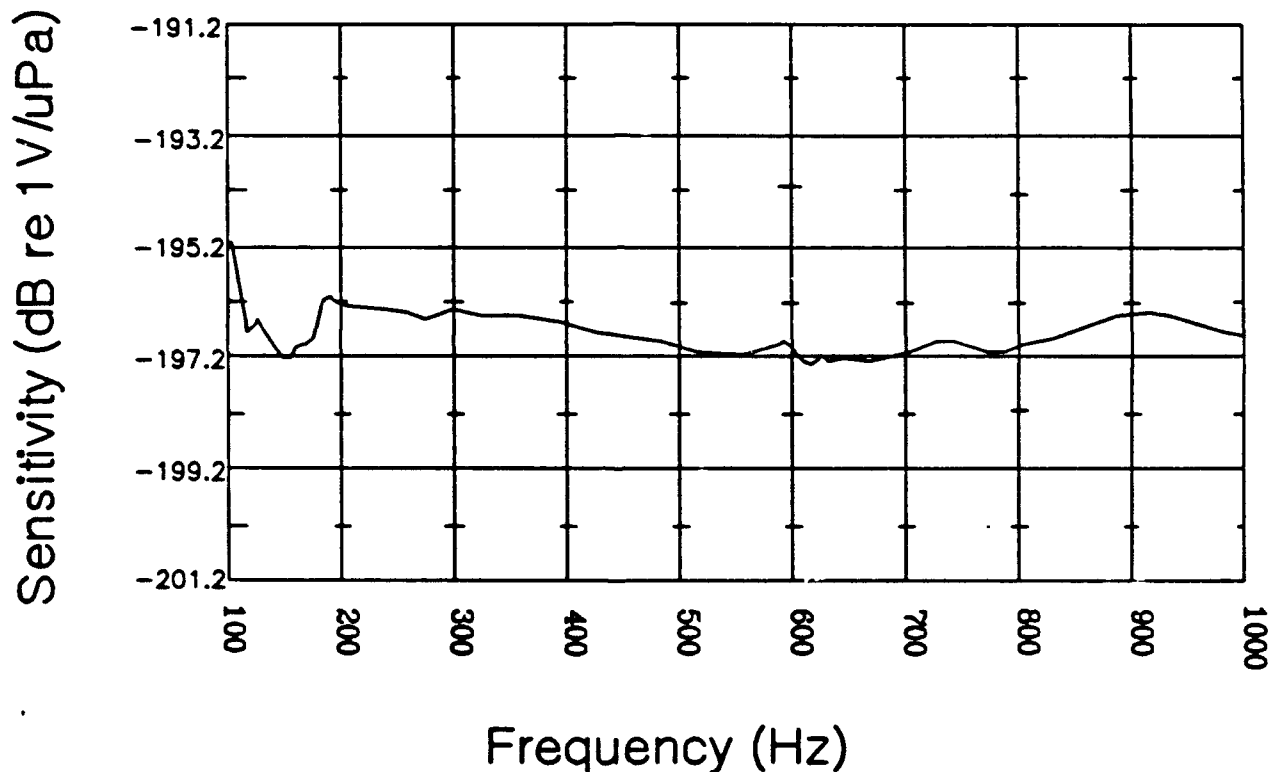


Fig. 4 - Typical H52 QFFVS using the G40 calibrator.

To maintain the accuracy of this measurement, a reference standard hydrophone (USRD type H56) is used periodically to test the reference standard transducer (F61) to verify its calibration. If a discrepancy is found, the F61 is recalibrated and/or replaced.

### Immittance Tests

The admittance and impedance tests are measured directly by the analyzer. The computer controls the analyzer and stores and displays the data for the user. Typical output is shown in Fig. 5. The admittance and impedance are both scalar values derived from the real and imaginary components measured from a signal input to the unit under test from the analyzer. These measurements are not the same as those made by the calibration facility because the Standards Section does not have a test tank in which to obtain the mass loading of the water. This loading shifts the resonance and dampens the rest of the admittance or impedance curve. Even though this test is done in air (without water loading), it can identify a defective unit by comparing it to a good or "typical" unit that was also tested in air.

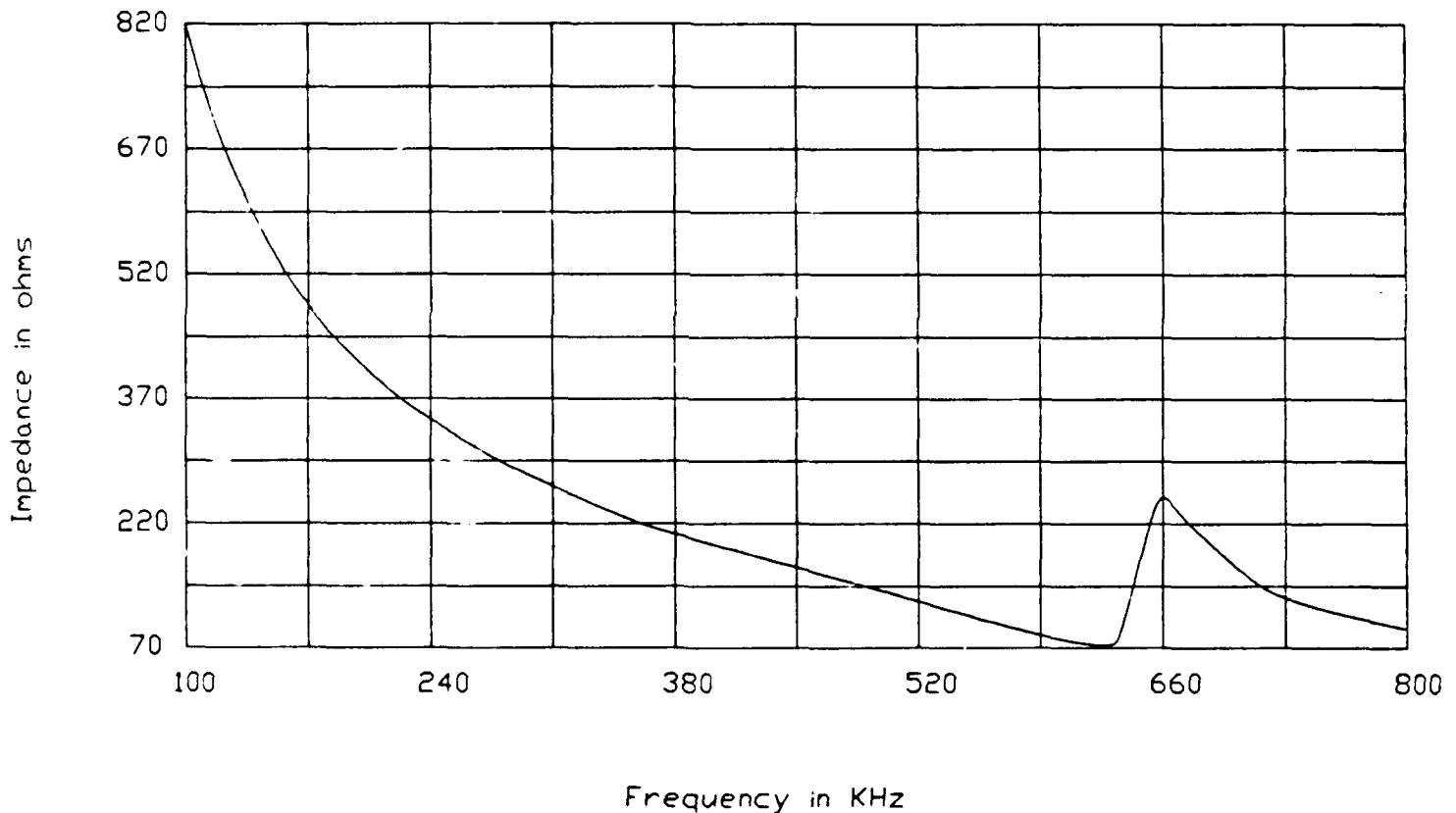


Fig. 5 - Typical impedance graph of a USRD type E27 transducer.

## CONCLUSION

The computer-controlled HP-4194A impedance/gain-phase Analyzer can be used as a tool to augment the reliability of precal tests. This has been accomplished through the development of user-friendly computer initial software USRD to configure as well as control the analyzer.

The system has been operating reliably for two years in the NRL-USRD Standards Section. The deviation of the gain-phase test data from the actual calibration data at the USRD Lake Facility is typically 0.6 dB. The system has helped to reduce calibration costs to the Standards Section by identifying defective transducers before they are sent to the Lake Facility for calibration. Even though the acoustical gain-phase test is limited to relatively low frequencies, the admittance/impedance test can be used over a much wider bandwidth. This bandwidth is sufficient to identify defective transducers by showing shifts in resonance frequencies or anomalies that would otherwise show up in the calibration curve. The system has also helped to shorten standard transducer repair time by using it for troubleshooting defective units.

The precal system software is being updated and improved to meet the changing needs of NRL-USRD transducers. Further tests can be added according to the requirements for testing new transducer standards or to improve the system's effectiveness in troubleshooting existing standards.

Copies of the software and a user's manual are available on request from:

Standards Section (Code 5978)  
Transducer Branch  
Underwater Sound Reference Detachment  
Naval Research Laboratory  
P.O. Box 568337  
Orlando, FL 32856-8337.

## ACKNOWLEDGMENTS

The authors wish to express their appreciation to the NRL-USRD Development Section of the Transducer Branch (Code 5977) for providing the software to control the HP-4194A analyzer and transfer the data. Portions of their code were used as examples to write the current GPM and IMMITTANCE programs. Appreciation is also expressed to Mr. A. J. Farley for his unique ability to find software bugs.

## REFERENCES

1. Robert J. Bobber, *Underwater Electroacoustic Measurements*, (U.S. Government Printing Office, 1970) pp. 136-138 (DTIC AD# 717 318).
2. Ibid, pp. 18-20.
3. C. C. Sims, "Hydrophone Calibrator," Navy Underwater Sound Reference Laboratory Research Report No. 60, 12 Apr 1962 (DTIC AD# 279 904).

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4. G. D. Hugus, III, and I. D. Groves, Jr., "Hydrophone Calibrator for Ship-board Use," *J. Acoust. Soc. Am.* **56**, pp. 70-74 (1974).
5. Hewlett-Packard Report #HP 04194-90001, "4194A Impedance/Gain-Phase Analyzer Operation Manual," Apr 1986.

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## APPENDIX

### Computer Program Flow Charts

#### GENERAL PROGRAM

Once the hardware is set up and configured as described in this document, a technician can make the computer-controlled measurements. The computer software, available upon request from NRL-USRD, is user friendly. The general flow chart shown in Fig. A-1 indicates the procedures common to the GPM and IMMITTANCE programs. A technician can manipulate the program using function keys for simple "yes" and "no" responses. The users manual, also available upon request from USRD, describes in detail the procedures to follow for initializing and operating the programs.

The measurement system is broken down into two main programs:

- The GPM program, which measures the hydrophone coupling gain and the QFFVS of a transducer using the laboratory calibrator.
- The IMMITTANCE program, which measures the impedance and admittance of the transducer.

#### GAIN-PHASE MEASUREMENT

The gain-phase measurement flow chart is shown in Fig. A-2. This is the section labeled "Gain-Phase Measurement" in the general flow chart. The program guides the operator through a choice of hydrophone voltage coupling gain measurements or QFFVS measurements.

Options within the program consist of a 9-point coupling test, a 401-point coupling sweep, or a 401-point frequency sweep. The acquired data can be plotted, tabulated, and/or stored. The program will also allow the user to view or plot old data previously stored in the data base.

When either of the coupling tests is chosen, the VHF switch is automatically set to the toroidal transformer to execute a coupling gain test through the preamplifier via the calibration circuit. When the Frequency Sweep test is chosen, a QFFVS measurement is made on the test hydrophone. If you want to change the parameters of this test, choose the Change Parameters option. See Fig. A-3 for more information. When the data are stored, the computer automatically creates the file name under which the data are stored and places it in the appropriate directory and subdirectory of the data base.

#### CHANGE SWEEP PARAMETERS

The "Change Sweep Parameters" option allows a change of any of the sweep parameters of the tests. With the exception of the coupling points test, these changes do not affect the default values. They remain changed until the program is stopped and rerun or until a new type of hydrophone is selected. A



user will not have to change the parameters for these tests under normal conditions; however, the options are available should the change be desired.

As the flow chart in Fig. A-3 indicates, there are eight parameters that can be changed. The "integration time" option toggles between short, medium, and long integration times. This affects the duration of the measurement.

The averaging number designates how many samples are to be averaged for each data point. The averaging number can be from 1 to 256. The default averaging number is 4. With an increased averaging number, the plot will be smoother due to reduced noise (more samples are averaged). The higher the averaging number, the longer the test will take to complete.

## **IMMITTANCE**

The IMMITTANCE program flow chart is shown in Fig. A-4. This program controls the HP-4194A to measure admittance and impedance on standard piezoelectric transducers. To conduct these tests manually, one would have to know the frequency characteristics of each transducer and set up the analyzer appropriately.

After the transducer name and serial number are entered (Fig. A-1), the program will display the options shown in the flow chart. If one of the tests is selected, the computer will automatically configure the analyzer for the appropriate test. This is accomplished by reading the sweep parameters, "typical" data, and necessary rigging information from the data base. The information is sent to the analyzer, the measurement is made, and the data are transferred to the computer.

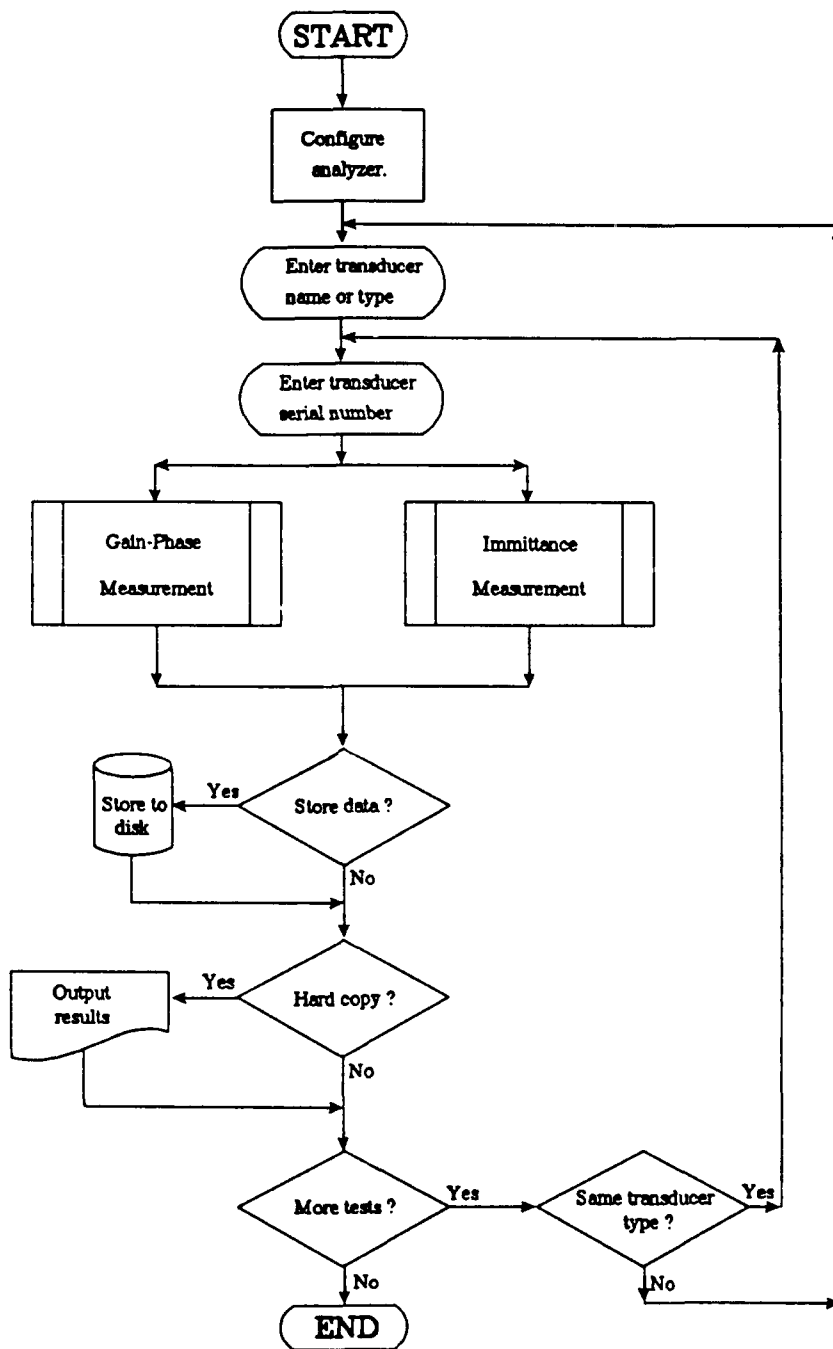


Fig. A-1 - General flow chart of the measurement programs.

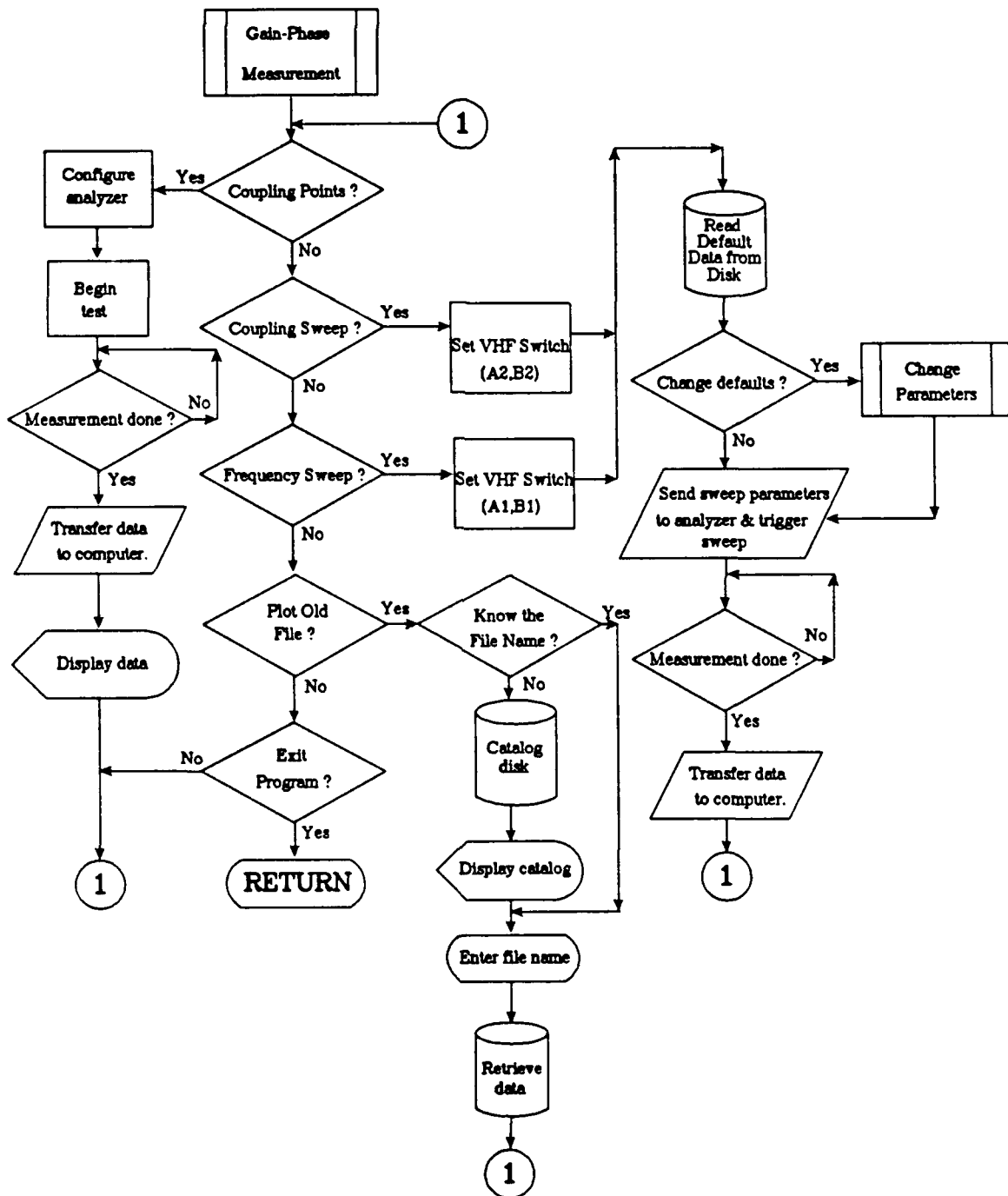


Fig. A-2 - Gain-phase measurement flow chart.

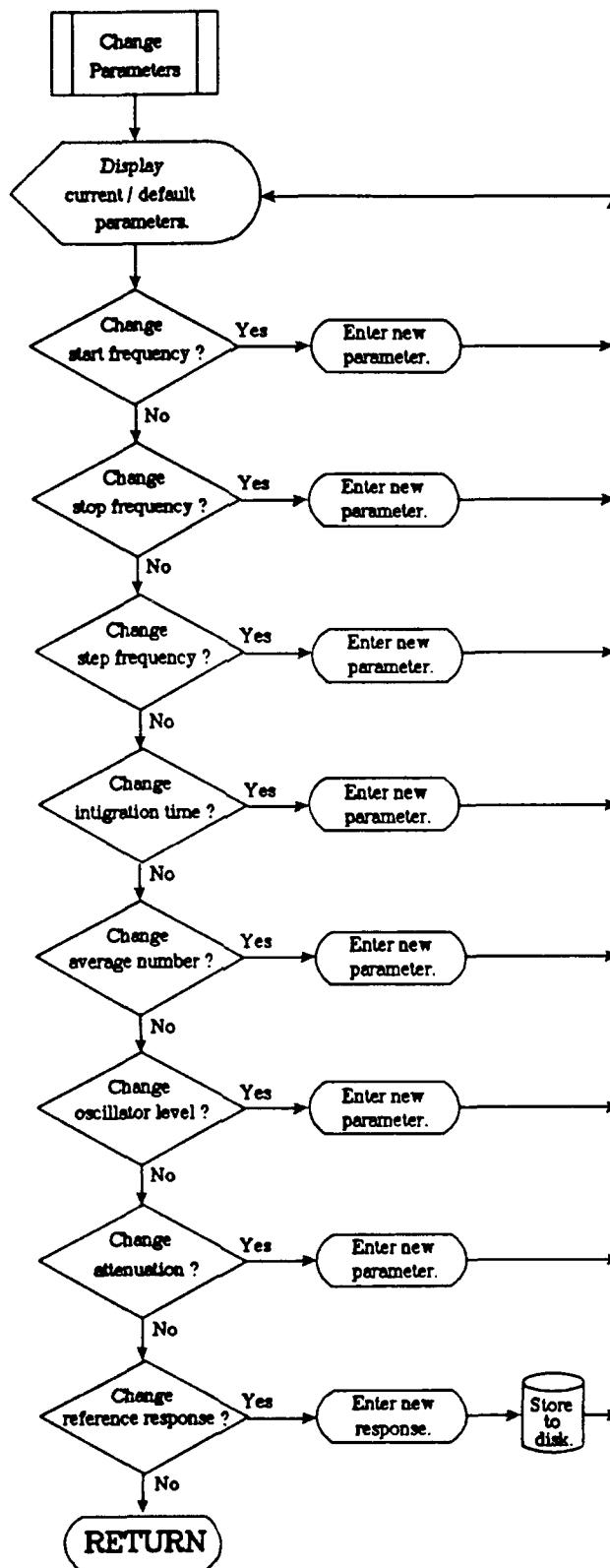


Fig. A-3 - Change sweep parameters flow chart.

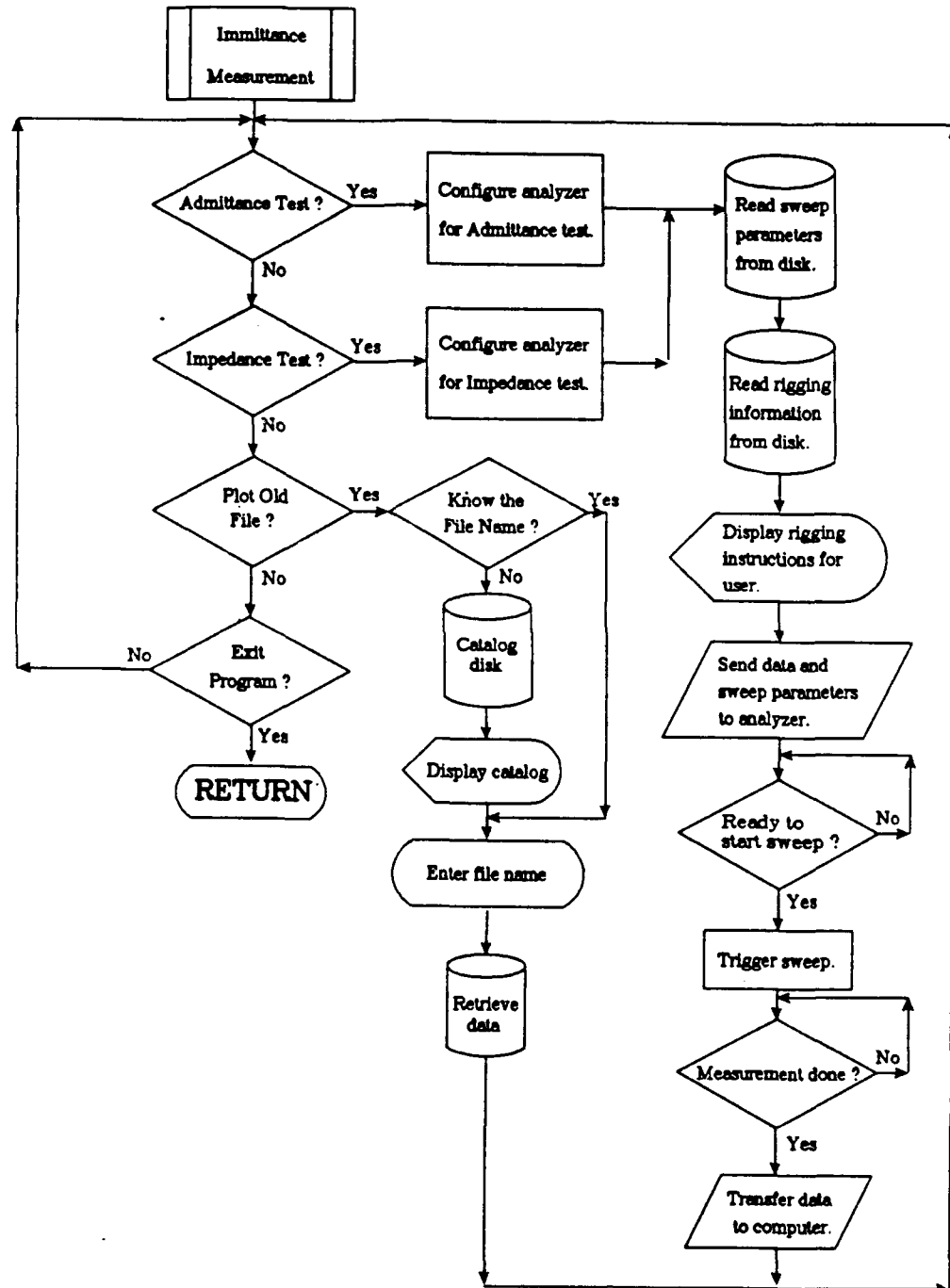


Fig. A-4 - Immittance program flow chart.

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**SUPPLEMENTARY**

**INFORMATION**

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## CONCLUSION

The computer-controlled HP-4194A impedance/gain-phase Analyzer can be used as a tool to augment the reliability of precal tests. This has been accomplished through the development of user-friendly computer software to configure as well as control the analyzer.

The system has been operating reliably for two years in the NRL-USRD Standards Section. The deviation of the gain-phase test data from the actual calibration data at the USRD Lake Facility is typically 0.6 dB. The system has helped to reduce calibration costs to the Standards Section by identifying defective transducers before they are sent to the Lake Facility for calibration. Even though the acoustical gain-phase test is limited to relatively low frequencies, the admittance/impedance tests can be used over a much wider bandwidth. This bandwidth is sufficient to identify defective transducers by showing shifts in resonance frequencies or anomalies that would otherwise show up in the calibration curve. The system has also helped to shorten standard transducer repair time by using it for troubleshooting defective units.

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2. Ibid, pp. 18-20.
3. C. C. Sims, "Hydrophone Calibrator," Navy Underwater Sound Reference Laboratory Research Report No. 60, 12 Apr 1962 (DTIC AD# 279 904).